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Thomas Stafford
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PATENT APPLICATION

INVENTOR(s) Rajiv Laroia
Junyi Li
Sundeep Rangan
Pramod Viswanath

CASE: 15-8-4-1

TITLE: COMMUNICATIONS SYSTEM EMPLOYING ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING BASED SREAD SPECTRUM MULTIPLE ACCESS

ASSISTANT COMMISSIONER FOR PATENTS
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SIR:
Enclosed are the following papers relating to the above-named application for patent:

22 Page specification and claims
4 Sheets of Informal drawings
Unexecuted Declaration and Power of Attorney
Information Disclosure Statement and Documents

CLAIMS AS FILED

	No. Filed	No. Extra	Rate	Calculations
Total Claims	48-20 =	28	x $18 =	504
Independent Claims	3 - 3 =	0	x $78 =	0
Multiple Dependent Claim(s), if applicable	0		$270 =	0
Basic Fee				690
			TOTAL FEE	**1194**

Please file the application and charge **Lucent Technologies Deposit Account No. 12-2325** the above-indicated amount, to cover the filing fee. Duplicate copies of this letter are enclosed. In the event of non-payment or improper payment of a required fee, the Commissioner is authorized to charge or to credit Deposit Account No.12-2325 as required to correct the error.

Please address all correspondence to **Thomas Stafford, 4173 Rotherham Court, Palm Harbor, Florida 34685**. Telephone calls should be made to Thomas Stafford at 727-772-4173 and FAX calls at 727-772-2545.

Respectfully,
Rajiv Laroia
Junyi Li
Sundeep Rangan
Pramod Viswanath

By _____
THOMAS STAFFORD
Attorney for Applicants
Reg. No. 24767
727-772-4173

Date: 04/18/2000

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BASE STATION IDENTIFICATION IN ORTHONGONAL FREQUENCY DIVISION MULTIPLEXING BASED SPREAD SPECTRUM MULTIPLE ACCESS SYSTEMS

Related Application

United States Patent application Serial No. (R. Laroia-J. Li-S. V. Uppala Case 16-9-4) was filed concurrently herewith.

Technical Field

This invention relates to wireless communications systems and, more particularly, to orthogonal frequency division multiplexing (OFDM) based spread spectrum multiple access (SSMA) systems.

Background of the invention

It is important that wireless communications systems be such as to maximize the number of users that can be adequately served and to maximize data transmission rates, if data services are provided. Wireless communications systems are typically shared media systems, i.e., there is a fixed available bandwidth that is shared by all users of the wireless system. Such wireless communications systems are often implemented as so-called "cellular" communications systems, in which the territory being covered is divided into separate cells, and each cell is served by a base station.

In such systems, it is important that mobile user units are rapidly able to identify and synchronize to the downlink of a base station transmitting the strongest signal. Prior arrangements have transmitted training symbols periodically for mobile user units to detect and synchronize to the associated base station downlink. In such arrangements, there is a large probability that delays occur in identifying the base station transmitting the strongest signal because the training symbols are typically transmitted at the beginning of a frame. It is also likely that the training symbols transmitted from different base stations would interfere with each other. Indeed, it is known that once the training symbols interfere with each other they will continue to interfere. Thus, if the training symbols are corrupted, then the data is also corrupted, thereby causing loss in efficiency.

Summary of the Invention

Problems and/or limitations related to prior mobile user units that have attempted to identify a base station having the strongest downlink signal are addressed by utilizing a pilot tone hopping sequence being transmitted by a base station. Specifically, base station identification is realized by determining the slope of the strongest received pilot signal, i.e., the received pilot signal having the maximum energy.

In an embodiment of the invention, the pilot tone hopping sequence is based on a Latin Squares sequence. With a Latin Squares based pilot tone hopping sequence, all a mobile user unit needs is to locate the frequency of the pilot tones at one time because the pilot tone locations at subsequent times can be determined from the unique slope of the Latin Squares pilot tone hopping sequence. The slope and initial frequency shift of the pilot tone hopping sequence with the strongest received power is determined by employing a unique maximum energy detector. This unique slope of the pilot tone hopping sequence is then advantageously employed to identify the base station having the strongest downlink signal.

In one embodiment, the slope and initial frequency shift of the pilot signal having the strongest received power is determined by finding the slope and initial frequency shift of a predicted set of pilot tone locations having the maximum received energy.

In another embodiment, the frequency offset of the pilot signal with the strongest, i.e., maximum, received power is estimated at each of times "t". These frequency offsets are employed in accordance with a prescribed relationship to determine the unknown slope and the initial frequency shift of the pilot signal.

A technical advantage to using the pilot tone hopping sequence to identify the base station having the strongest downlink signal is that the inherent latency resulting from using a sequence of training symbols is not present.

Brief Description of the Drawing

FIG. 1 illustrates a frequency domain representation in which a prescribed plurality of tones is generated in a prescribed bandwidth;

FIG. 2 illustrates a time domain representation of a tone f_i;

FIG. 3 is a graphical representation of a time-frequency grid including a pilot tone hopping sequence;

FIG. 4 is a graphical representation of a Latin Squares hopping sequence;

FIG. 5 shows, in simplified block form, an OFDM-SSMA cellular system with Latin Squares pilots;

FIG. 6 shows, in simplified block diagram form, details of a mobile user unit in which an embodiment of the invention may advantageously be employed;

FIG. 7 shows, in simplified block diagram for, details of an embodiment of a maximum energy detector that may be employed in the mobile user unit of FIG. 6;

FIG. 8 shows, in simplified block diagram form, details of another embodiment of a maximum energy detector that may be employed in the mobile user unit of FIG. 6; and

FIG. 9 is a flow chart illustrating steps in a process that may be employed in the slope-shift solver of FIG. 8.

Detailed Description

FIG. 1 illustrates a frequency domain representation in which a prescribed plurality of tones is generated in a prescribed bandwidth. In this example, bandwidth W is employed to generate a total of N tones, i.e., $i=1,\ldots,N$. The tones are spaced at $\Delta f = 1/T_S$ apart, where T_s is the duration of an OFDM symbol. Note that the tones employed in this embodiment of the invention are generated differently than those generated for a narrow band system. Specifically, in a narrow band system the energy from each tone is strictly confined to a narrow bandwidth centered around the tone frequency, whereas in an Orthogonal Frequency Division Multiplexing (OFDM) system that is a wide band system the energy at a particular tone is allowed to leak into the entire bandwidth W, but it is so arranged that the tones do not interfere with one another.

FIG. 2 illustrates a time domain representation of tone f_i within symbol interval T_s. Again, note that within each symbol interval T_s, data may be transmitted on each of the tones substantially simultaneously.

FIG. 3 is a graphical representation of an example OFDM channel from a base station to a number of mobile user units, i.e., receivers. The OFDM channel is represented as a time-frequency grid, i.e., plane. Each column of the grid represents the time interval for one OFDM symbol interval, and each OFDM symbol is comprised of a number of tones. In this example, there are $N=5$ tones in each symbol interval. The

tones are numbered along the frequency axis and the symbol intervals, i.e., periods, are numbered along the time axis. If the spacing between tones in FIG. 3 is Δf, then:

tone 0 corresponds to f;

tone 1 corresponds to $f + \Delta f$;

tone 2 corresponds to $f + 2\Delta f$;

tone 3 corresponds to $f + 3\Delta f$;

tone 4 corresponds to $f + 4\Delta f$.

Similarly, if the duration of a symbol interval is T_s then:

time 0 corresponds to t_0;

time 1 corresponds to $t_0 + T_s$;

time 2 corresponds to $t_0 + 2T_s$;

time 3 corresponds to $t_0 + 3T_s$;

time 4 corresponds to $t_0 + 4T_s$;

time 5 corresponds to $t_0 + 5T_s$;

time 6 corresponds to $t_0 + 6T_s$.

In general, a pilot signal includes known waveforms that are transmitted from a base station so that mobile user units, i.e., receivers, can identify the base station and estimate various channel parameters. In an Orthogonal Frequency Division Multiplexing based Spread Spectrum Multiple Access (OFDM-SSMA) system, in accordance with an aspect of the invention, the pilot signal is comprised of known symbols transmitted on prescribed tones during prescribed symbol intervals. In a given symbol interval, the tones used for the pilot signal are called the "pilot tones", and the assignment of pilot tones as a function of time is called the "pilot hopping sequence". Again, it is noted that the inherent delays resulting when using the training sequence of symbols is not experienced when using the pilot tone hopping sequence to identify the base station having the strongest downlink signal.

Since the OFDM-SSMA physical layer is based on the pilot signals, symbols on the pilot tones are transmitted at higher power than symbols on non-pilot tones. Pilot tones are also boosted in power so that they may be received throughout the cell.

Therefore, for the purpose of identification, pilot signals can be distinguished by the fact that the energy received on the pilot tones is higher than the energy on the non-pilot tones.

In FIG. 3, an example set of pilot tones is indicated by the hatched squares in the time-frequency grid. In this example, the base station transmits one pilot tone in each OFDM symbol interval. During: symbol interval (0), tone (1) is used as a pilot tone; symbol interval (1), tone (4) is used as a pilot tone; symbol interval (2), tone (0) is used as a pilot tone; symbol interval (3), tone (2) is used as a pilot tone; symbol interval (4), tone (4) is used as a pilot tone; symbol interval (5), tone (1) is used as a pilot tone; etc...

FIG. 4 shows an example of a Latin Squares pilot hopping sequence. The pilot signal corresponding to a Latin Squares pilot hopping sequence will be called a "Latin Squares pilot signal", or simply "Latin Squares pilot". In a Latin Squares pilot hopping sequence, the number of tones, N, is a prime number, and the pilot signals are transmitted on a fixed number, N_p, of the N tones in each OFDM symbol interval. The tone number of the j-th pilot tone in the t-th symbol interval is given by,

$$\sigma_S(j,t) = st + n_j \pmod N, \quad j = 1,...,N_p, \qquad (1)$$

where s and n_j are integers. A Latin Squares pilot signal of the form of Equation (1) can be viewed as a set of N_p parallel, cyclically rotating lines in a prescribed time-frequency grid, i.e., plane. The parameter, s, is the *slope* of the lines and the parameters, n_j, are the *frequency offsets*. In the example Latin Squares pilot hopping in FIG. 4, N =11, $N_p = 2$, $n_1 = 1$, $n_2 = 5$ and s=2.

The frequency offsets and slope are design parameters of the Latin Squares pilot signal. For the purpose of channel estimation, the frequency offsets and slope should be selected so that the pilot tones are close to uniformly distributed in the time-frequency plane. A uniform distribution minimizes the worst-case interpolation error in the channel estimation. Specific values for the frequency offsets and slopes can be tested by numerical simulation with a specific channel estimator and channel conditions.

FIG. 5 depicts an OFDM-SSMA cellular system using Latin Squares pilots. The figure shows two base stations 501 and 502 in the cellular system, denoted BS1 and BS2, respectively. Each base station 501, 502 in the cellular system transmits a Latin Squares

pilot. A mobile user unit 503, denoted MS, receives pilots signals and other transmissions from one or more base stations in the cellular system. The Latin Squares pilots transmitted by all the base stations 501, 502 use the same total number of tones, *N,* number of pilot tones per OFDM symbol, N_p, and the frequency offsets, n_j. However, the slope, *s,* of each pilot signal is locally unique in the sense that no two neighboring base stations use the same slope. Each slope, *s,* is taken from some set $S \subset \{0,1,...,N-1\}$. The use of locally unique slopes minimizes collisions between pilot signals from neighboring base stations. In addition, the slope provides a unique identifier for each base station. In FIG. 6, the slope of the pilot signal from BS1 (501) is denoted s_1, and the slope of the pilot signal from BS2 (502) is denoted s_2.

The base station identification problem is for the mobile user unit 503 to estimate the slope, $s \in S$, of the strongest received pilot signal. To perform this identification, the mobile user unit 503 can be pre-programmed with the common pilot signal parameters, N, N_p and n_j, as well as the set of possible slopes, *S.*

In general, base station identification is conducted prior to downlink and carrier synchronization. Consequently, a mobile user unit 503 may receive the pilot signals with unknown frequency and timing errors, and mobile user units must be able to perform base station identification in the presence of these errors. Also, after identifying the pilot hopping sequence of the strongest base station, the mobile user unit must synchronize its timing and carrier so that the location of subsequent pilot tones can be determined.

To define this synchronization problem more precisely, let Δt denote the timing error between a base station and mobile user unit in number of OFDM symbol intervals, and Δn denote the frequency error in number of tones. For the time being, it is assumed that Δt and Δn are both integer errors. Fractional errors will be considered later. Under integer time and frequency errors, Δt and Δn, if a base station transmits a pilot sequence given by Equation (1), the *j*-th pilot tone in the *t*-th symbol interval of the mobile will appear on tone number,

$$\sigma_S(j, t+\Delta t) + \Delta n = b(t) + n_j, \qquad (2)$$

where,

$$b(t) = s(t+\Delta t) + \Delta n, \qquad (3)$$

and where *b(t)* is the pilot frequency shift at time *t*. Equation (2) shows that if the frequency shift *b(t)* is known, the locations of the pilot tones at *t* are known. Also, if the frequency shift is determined at any one time, say *b(0)*, the frequency shift at other times can be determined from $b(t) = b(0)+st$. Therefore, for synchronization, it suffices to estimate the frequency shift at any one time. The value *b(0)* will be called the initial frequency shift.

The fact that synchronization requires only the estimation of the initial frequency shift is a particular and useful feature of the Latin Square pilot hopping sequences. In general, synchronization involves estimation of time and frequency errors, and therefore demands a two parameter search. Synchronization for the Latin Squares sequences considered here, however, only requires the estimation of one parameter.

In summary, in an OFDM-SSMA cellular system, each base station transmits a Latin Squares pilot signal with a locally unique slope. A mobile user unit performs base station identification by estimating the slope of the strongest received pilot signal. In addition, the mobile user unit can synchronize to the pilot signal by estimating its initial frequency shift.

FIG. 6 shows, in simplified block diagram form, the details of a mobile user unit 600 containing the proposed maximum energy detector for base station identification. An incoming signal is supplied via an antenna 601 to a down conversion unit 602. The incoming signal includes pilot signals from one or more base stations. Down conversion unit 602 yields the baseband signal *r(t)* from the signal received by the mobile user unit 600. The received signal *r(t)* is supplied to fast Fourier transform (FFT) unit 603 that during each OFDM symbol interval performs an FFT on it to yield *Y(t,n)*. In this example, *Y(t,n)* denotes the complex value received on the *n*-th tone in the *t*-th symbol interval and is supplied to maximum energy detector 604 and to receiver 605. Maximum energy detector 604 uses FFT data *Y(t,n)* from N_{sy} consecutive OFDM symbols to estimate the slope and initial frequency shift of the pilot signal with the maximum received strength. As indicated above, the FFT symbols to be used for the base station identification are denoted *Y(t,n)*, $t = 0,..., N_{sy} - 1$ and *n=0,...,N-1*, and the estimates of the slope and initial frequency shift of the strongest received pilot signal are denoted $\hat{s}$ and

$\hat{b}_0$, respectively. The pilot slope $\hat{s}$ and initial frequency shift $\hat{b}_0$ estimates are supplied to a receiver 605 and employed to synchronize receiver 605 to the incoming carrier and to locate subsequent symbols in the pilot signal.

FIG. 7 shows, in simplified block diagram form details of an embodiment of a maximum energy detector 604 that may be employed in the mobile user unit 600 of FIG. 6. It has been seen that for the Latin Squares pilot tones, each candidate slope, *s*, and initial frequency shift, $b_0 = b(0)$, corresponds to a set of predicted pilot tone locations, *(t,n)*, with

$$n = st + b_0 + n_j, \qquad j = 1,\ldots,N_p, \quad t = 0,\ldots,N_{sy} - 1. \tag{4}$$

Symbols on these pilot tones should be received with greater power than the symbols on the non-pilot tones. That is, the energy, $|Y(t,n)|^2$, should on average be highest on the pilot tones of the pilot signal with the strongest received signal strength. Therefore, a natural way to estimate the slope and frequency shift of the strongest pilot signal is to find the slope and frequency shift for which there is a maximum received energy on the predicted set of pilot tone locations of Equation (4). The input to the maximum energy detector 604 of FIG. 6 is the FFT data, $Y(t,n), t = 0,\ldots,N_{sy} - 1$ and *n=0,...,N-1*. The slope-shift accumulator 701, accumulates the energy along each possible slope, *s,* and initial frequency shift, b_0. The accumulated energy is given by the signal:

$$J_0(s,b_0) = \sum_{t=0}^{N_{sy}-1} |Y(t, st + b_0 (\mathrm{mod}\, N))|^2 . \tag{5}$$

Then, frequency shift accumulator 702 accumulates the energy along the pilot frequency shifts, namely:

$$J(s,b_0) = \sum_{j=1}^{N_p} J_0(s, b_0 + n_j). \tag{6}$$

Maximum detector 703 estimates the slope and frequency shift of the maximum energy pilot signal as the slope and frequency shifts corresponding to the maximum accumulated pilot energy, that is:

$$\hat{s}, \hat{b}_0 = \arg\max_{s,b_0} J(s,b_0), \tag{7}$$

where the maximum is taken over $s \in S$ and $b_0 = 0,...,N-1$.

Unfortunately, in certain applications, the above computations of Equations (5), (6) and (7) may be difficult to perform in a reasonable amount of time with the processing power available at the mobile user unit 600. To see this, note that to compute $J_0(s,b_0)$ in Equation (5) at a single point (s,b_0) requires N_{sy} additions. Therefore, to compute $J_0(s,b_0)$ at all (s,b_0) requires $NN_{sl}N_{sy}$ additions, where N_{sl} is the number of slopes in the slope set S. Similarly, computing $J(s,b_0)$ in Equation (6) requires $NN_{sl}N_p$ additions. Therefore, the complete energy detector would require $O(NN_{sl}(N_p + N_{sy}))$ basic operations to perform. Therefore, for typical values such as N=400, N_{sl}=200, N_p=10 and N_{sy}=20, the full energy detector would require 2.4 million operations. This computation may be difficult for the mobile user unit 600 to perform in a suitable amount of time.

FIG. 8 shows, in simplified block diagram form details of another embodiment of a maximum energy detector that may be employed in the mobile user unit of FIG. 6. Symbolwise shift detector 801 estimates, at each time *t*, the frequency shift of the pilot signal with strongest received strength. Specifically, the block computes:

$$[E(t),n(t)] = \max_n \sum_{j=1}^{N_p} |Y(t,n+n_j \pmod N)|^2 \quad , \qquad (8)$$

where *E(t)* is the maximum energy value and *n(t)* is the argument of the maximum. To understand the purpose of the computation in Equation (8), suppose that the tones of the strongest energy pilot signal appear at the locations, *(t,n)*, given in Equation (4). Since the received energy $|Y(t,n)|^2$, will usually be maximum at these pilot tone locations, the maximization in Equation (9) will typically result in:

$$n(t) = st + b_0 \pmod N, \qquad (9)$$

and *E(t)* will typically be the pilot signal energy at the time *t*. The value *n(t)* in Equation (9) is precisely the frequency shift estimate of the pilot signal at time *t*. Note that *n(t)* is sometimes referred to as the symbolwise frequency shift estimate.

Slope-shift solver 802 uses the relation in Equation (9) and the frequency offset estimates, *n(t)*, to determine the unknown slope, *s*, and initial frequency shift, b_0. Since,

the pilot signals are only on average higher in power than the non-pilot tones, the relation of Equation (9) may not hold at all time points *t*. Therefore, the slope-shift solver 802 must be robust against some of the data points *n(t)* not satisfying Equation (9). For robustness, the value *E(t)* can be used as measure of the reliability of the data *n(t)*. Larger values of *E(t)* imply a larger amount of energy captured at the frequency shift estimate, *n(t)*, and such values of *n(t)* can therefore be considered more reliable.

One possible way of implementing a robust slope-shift solver 802 is referred to as the *difference method.* This method uses the fact that if *n(t)* and *n(t-1)* both satisfy Equation (10), then *n(t)-n(t-1)=s.* Therefore, the slope, *s*, can be estimated by:

$$\hat{s} = \arg\max_{s \in S} \sum_{t=1}^{N_{sy}-1} E(t)\mathbf{1}_{\{n(t)-n(t-1)=s\}} \qquad (10)$$

where **1** is the indicator function. The estimator as defined by Equation (10) finds the slope, *s*, on which the total received pilot energy, *E(t),* at the points, *t*, satisfying *n(t)-n(t-1)=s* is maximized. After estimating the slope, the initial frequency shift can be estimated by:

$$\hat{b}_0 = \arg\max_{b_0=0,\ldots,N-1} \sum_{t=0}^{N_{sy}-1} E(t)\mathbf{1}_{\{n(t)=st+b_0\}}. \qquad (11)$$

The difference method is the process given by Equations (10) and (11).

A second possible method for the slope-shift solver 802 is referred to as the *iterative test method.* FIG. 9 is a flow chart illustrating the steps for the iterative test solver

- Step 901: Start process.
- Step 902: Initialize $T = \{0, \ldots, N_{sy}-1\}$, and $E_{\max} = 0$.
- Step 903: Compute

$$\begin{aligned} t_0 &= \arg\max_{t \in T} E(t) \\ [E_0, s_0] &= \max_{s \in S} \sum_{t \in T} E(t)\mathbf{1}_{\{n(t)=n(t_0)+s(t-t_0)\}} \\ T_0 &= \{t \in T : n(t) = n(t_0) + s_0(t-t_0)\} \\ T &= T \setminus T_0 \end{aligned} \qquad (12)$$

where E_0 is the value of the maximum, i.e., strongest value, and s_0 is the argument of the maximum.

- Step 904: If $E_0 > E_{\max}$, go to step 905.
- Step 905: Set

$$\begin{aligned} E_{\max} &= E_0, \\ \hat{s} &= s_0, \\ \hat{b}_0 &= n(t_0) - s_0 t_0. \end{aligned} \tag{13}$$

Then, go to step 906.

- Step 904: If not go to step 906.
- Step 906: If T is non-empty return to step 903, otherwise END via step 907.

The values $\hat{s}$ and $\hat{b}_0$ in Step 905 are the final estimates for the slope and initial frequency shift of the strongest pilot signal.

The logic in the iterative test method is as follows. The set T is a set of times and is initialized in Step 902 to all the N_{sy} time points. Step 903 then finds the time, $t_0 \in T$, and slope, $s_0 \in S$, such that the set of times t on the line $n(t) = n(t_0) + s_0(t - t_0)$, has the largest total pilot signal energy. The points on this line are then removed from T. In Step 904, if the total energy on the candidate line is larger than any previous candidate line, the slope and frequency shift estimates are updated to the slope and frequency shifts of the candidate line in step 905. Steps 903 through 906 are repeated until all points have been used in a candidate line.

Both the difference method and iterative test method demand significantly less computational resources than the full maximum energy detector. In both methods, the bulk of the computation is in the initial symbolwise shift detection in Equation (8). It can be verified that to conduct this maximization at all the N_{sy} time points $N_{sy}NN_p$ operations. Therefore, for the values N=400, N_p=10 and N_{sy}=20, the simplified maximum energy detector would require 80000 operations, which is considerably less than the 2.4 million needed by the full energy detector.

The above base station identification methods can be further simplified by first quantizing the FFT data *Y(t,n)*. For example, at each time *t*, we can compute a quantized value of *Y(t,n)* given by:

$$Y_q(t,n) = \begin{cases} 1 & \text{if } |Y(t,n)|^2 > q\mu(t) \\ 0 & \text{else} \end{cases} \tag{15}$$

where $q>1$ is an adjustable quantization threshold, and $\mu(t)$ is the mean received energy at time t:

$$\mu(t)=\frac{1}{N}\sum_{n=0}^{N-1}|Y(t,n)|^2. \qquad (16)$$

The quantized value $Y_q(t,n)$ can then be used in place of $|Y(t,n)|^2$ in the above base station identification processes. If the parameter q is set sufficiently high, $Y_q(t,n)$ will be zero at most values of n, and therefore the computations such as Equation (8) will be simplified.

In the above discussion, it has been assumed that the time error between the base station and mobile is some integer number of OFDM symbol intervals, and the frequency error is some integer number of tones. However, in general both the time and frequency errors will have fractional components as well. Fractional errors result in the pilot tones being split between two time symbols and spread out in frequency. This splitting reduces the pilot power in the main time-frequency point, making the pilot more difficult to identify. Meanwhile, without proper downlink synchronization, data signals from the base station are not received orthogonally with the pilot signal, thus causing extra interference in addition to that generated by neighboring base-stations. Overall, fractional time and frequency errors can thereby significantly degrade the base station identification. In particular, the strongest energy detection process may not perform well.

To avoid this fractional problem, the above identification processes be run at several fractional offsets. Specifically, for a given received signal *r(t),* the mobile user unit can slide the FFT window $N_{fr,t}$ times along the time axis, each time obtaining a different set of frequency sample vectors. The step size of sliding the FFT window should be $1/N_{fr,t}$ of the symbol interval. Similarly, the mobile user unit can slide the FFT window $N_{fr,f}$ times along the frequency axis with a spacing of $1/N_{fr,f}$ of a tone. The identification process can be run on the frequency samples obtained from each of the fractional time and frequency offsets. This process yields $N_{fr,t}N_{fr,f}$ candidate slope and frequency shifts.

To determine which of the $N_{fr,t}N_{fr,f}$ candidate slope and shifts to use, the mobile user can select the slope and shift corresponding to the strongest pilot energy. For a given candidate (s,b_0) the pilot energy is given by $J(s,b_0)$ in Equation (6). If the difference method is used, an approximation for the pilot energy is given by the value of the strongest attained in equation (11). The value $E_{\max}$ may be employed in the iterative test method.

The above-described embodiments are, of course, merely illustrative of the principles of the invention. Indeed, numerous other methods or apparatus may be devised by those skilled in the art without departing from the spirit and scope of the invention.

0954080-041800

What is claimed is:

1. Apparatus for use in a mobile user unit in an orthogonal frequency division multiplexing (OFDM) based spread spectrum multiple access wireless system comprising:

a receiver for receiving one or more pilot tone hopping sequences each including pilot tones, said pilot tones each being generated at a prescribed frequency and time instants in a prescribed time-frequency grid; and

a detector, responsive to said one or more received pilot tone hopping sequences, for detecting the received pilot tone hopping sequence having strongest power.

2. The invention as defined in claim 1 wherein each of said one or more pilot tone hopping sequences is a Latin Squares based pilot tone hopping sequence.

3. The invention as defined in claim 1 wherein said receiver yields a baseband version of a received signal and further including a unit for generating a fast Fourier transform version of said baseband signal, and wherein said detector is supplied with said fast Fourier transform version of said baseband signal to determine a received pilot tone sequence having the strongest power.

4. The invention as defined in claim 3 wherein said receiver further includes a quantizer for quantizing the results of said fast Fourier transform.

5. The invention as defined in claim 3 wherein said detector is a maximum energy detector.

6. The invention as defined in claim 5 wherein said maximum energy detector determines a slope and initial frequency shift of pilot tones in a detected pilot tone hopping sequence having the strongest power.

7. The invention as defined in claim 6 wherein said maximum energy detector includes a slope-shift accumulator for accumulating energy along each possible slope and initial frequency shift of said one or more received pilot tone hopping sequences and generating an accumulated energy signal, a frequency shift accumulator supplied with said accumulated energy signal for accumulating energy along pilot frequency shifts of said one or more received pilot tone hopping sequences, and a maximum detector supplied with an output from said frequency shift accumulator for estimating a slope and

initial frequency shift of the strongest received pilot tone hopping sequence as a slope and initial frequency shift corresponding to he strongest accumulated energy.

8. The invention as defined in claim 7 wherein said accumulated energy is represented by the signal $J_0(s,b_0)$, where $J_0(s,b_0) = \sum_{t=0}^{N_w-1} |Y(t, st + b_0 (\text{mod } N))|^2$, and s is the slope of the pilot signal, b_0 is an initial frequency shift of the pilot signal, *Y(t,n)* is the fast Fourier transform data, $t = 0,..., N_{sy} - 1$, $n = st + b_0 (\text{mod } N)$, and $n = 0,...N\text{-}1$.

9. The invention as defined in claim 7 wherein said frequency shift accumulator accumulates energy along pilot frequency shifts of said one or more received pilot tone hopping sequences in accordance with $J(s,b_0) = \sum_{j=1}^{N_p} J_0(s, b_0 + n_j)$, where s is the slope of the pilot signal, b_0 is an initial frequency shift of the pilot signal and n_j are frequency offsets.

10. The invention as defined in claim 7 wherein said maximum detector estimates said slope and initial frequency shift of the strongest received pilot tone hopping sequence in accordance with $\hat{s}, \hat{b}_0 = \arg\max_{s,b_0} J(s,b_0)$, where $\hat{s}$ is the estimate of the slope, $\hat{b}_0$ is the estimate of the initial frequency shift, and where the maximum is taken over $s \in S$ and $b_0 = 0,..., N-1$.

11. The invention as defined in claim 6 wherein said maximum energy detector includes a frequency shift detector for estimating at a given time frequency shift of the received pilot tone hopping sequence having strongest energy and an estimated maximum energy value, and a slope and frequency shift solver, responsive to said estimated frequency shift and said estimated maximum energy value, for generating estimates of an estimated slope and an estimated initial frequency shift of the strongest received pilot signal.

12. The invention as defined in claim 11 wherein said estimated frequency shift at time t is obtained in accordance with $n(t) = st + b_0 (\text{mod } N)$, where s is the pilot signal slope, t is a symbol time and *n(t)* is a frequency shift estimate.

13. The invention as defined in claim 12 wherein said estimated maximum energy value is obtained in accordance with $[E(t),n(t)] = \max_{n} \sum_{j=1}^{N_p} | Y(t, n + n_j (\mathrm{mod}\, N)) |^2$, where $E(t)$ is the maximum energy value, $Y(t,n)$ is the fast Fourier transform data, $j = 1, \ldots, N_p$ and n_j are frequency offsets.

14. The invention as defined in claim 13 wherein said slope is estimated in accordance with $\hat{s} = \arg\max_{s \in S} \sum_{t=1}^{N_{sy}-1} E(t)\mathbf{1}_{\{n(t)-n(t-1)=s\}}$, where both $n(t)$ *and* $n(t\text{-}1)$ satisfy $n(t) = st + b_0 (\mathrm{mod}\, N)$.

15. The invention as defined in claim 13 wherein said frequency shift is estimated in accordance with $\hat{b}_0 = \arg \max_{b_0 = 0, \ldots, N-1} \sum_{t=0}^{N_{sy}-1} E(t)\mathbf{1}_{\{n(t)=st+b_0\}}$.

16. The invention as defined in claim 11 wherein said maximum energy detector detects said slope in accordance with determining the time, $t_0 \in T$, and slope, $s_0 \in S$, such that the set of times t on the line $n(t) = n(t_0) + s_0(t - t_0)$, has the largest total pilot signal energy.

17. A method for use in a mobile user unit in an orthogonal frequency division multiplexing (OFDM) based spread spectrum multiple access wireless system comprising the steps of:

receiving one or more pilot tone hopping sequences each including pilot tones, said pilot tones each being generated at a prescribed frequency and time instants in a prescribed time-frequency grid; and

in response to said one or more received pilot tone hopping sequences, detecting the received pilot tone hopping sequence having strongest power.

18. The method as defined in claim 17 wherein each of said one or more pilot tone hopping sequences is a Latin Squares based pilot tone hopping sequence.

19. The method as defined in claim 17 wherein said step of receiving yields a baseband version of a received signal and further including a step of generating a fast Fourier transform version of said baseband signal, and wherein said step of detecting is

responsive to said fast Fourier transform version of said baseband signal for determining a received pilot tone sequence having the strongest power.

20. The method as defined in claim 19 wherein said step of receiving further includes a step of quantizing the results of said fast Fourier transform.

21. The method as defined in claim 19 wherein said step of detecting detects a maximum energy.

22. The method as defined in claim 21 wherein said step of detecting said maximum energy includes a step of determining a slope and initial frequency shift of pilot tones in a detected pilot tone hopping sequence having the strongest power.

23. The method as defined in claim 22 wherein said step of detecting said maximum energy includes steps of accumulating energy along each possible slope and initial frequency shift of said one or more received pilot tone hopping sequences and generating an accumulated energy signal, in response to said accumulated energy signal, accumulating energy along pilot frequency shifts of said one or more received pilot tone hopping sequences, and in response to an output from said step of frequency shift accumulating, estimating a slope and initial frequency shift of the strongest received pilot tone hopping sequence as a slope and initial frequency shift corresponding to he strongest accumulated energy.

24. The method as defined in claim 23 wherein said accumulated energy is represented by the signal $J_0(s,b_0)$, where $J_0(s,b_0) = \sum_{t=0}^{N_{sy}-1} | Y(t, st + b_0 (\mathrm{mod}\, N)) |^2$, and s is the slope of the pilot signal, b_0 is an initial frequency shift of the pilot signal, *Y(t,n)* is the fast Fourier transform data, $t = 0, \ldots, N_{sy} - 1$, $n = st + b_0 (\mathrm{mod}\, N)$, and $n = 0, \ldots N\text{-}1$.

25. The method as defined in claim 23 wherein said step of frequency shift accumulating includes a step of accumulating energy along pilot frequency shifts of said one or more received pilot tone hopping sequences in accordance with $J(s,b_0) = \sum_{j=1}^{N_p} J_0(s, b_0 + n_j)$, where s is the slope of the pilot signal, b_0 is an initial frequency shift of the pilot signal and n_j are frequency offsets.

26. The method as defined in claim 23 wherein said step of maximum energy detecting includes a step of estimating said slope and initial frequency shift of the strongest received pilot tone hopping sequence in accordance with $\hat{s}, \hat{b}_0 = \arg\max_{s,b_0} J(s, b_0)$, where $\hat{s}$ is the estimate of the slope, $\hat{b}_0$ is the estimate of the initial frequency shift, and where the maximum is taken over $s \in S$ and $b_0 = 0,..., N-1$.

27. The method as defined in claim 22 wherein said step of maximum energy detecting includes a step of estimating at a given time frequency shift of the received pilot tone hopping sequence having strongest energy and estimating a maximum energy value, and in response to said estimated frequency shift and said estimated maximum energy value, generating estimates of an estimated slope and an estimated initial frequency shift of the strongest received pilot signal.

28. The method as defined in claim 27 wherein said estimated frequency shift at time t is obtained in accordance with $n(t) = st + b_0 (\mathrm{mod}\, N)$, where s is the pilot signal slope, t is a symbol time and *n(t)* is a frequency shift estimate.

29. The method as defined in claim 28 wherein said estimated maximum energy value is obtained in accordance with $[E(t), n(t)] = \max_n \sum_{j=1}^{N_p} | Y(t, n + n_j (\mathrm{mod}\, N)) |^2$, where *E(t)* is the maximum energy value, *Y(t,n)* is the fast Fourier transform data, $j = 1,..., N_p$ and n_j are frequency offsets.

30. The method as defined in claim 29 wherein said slope is estimated in accordance with $\hat{s} = \arg\max_{s \in S} \sum_{t=1}^{N_{sy}-1} E(t) \mathbf{1}_{\{n(t)-n(t-1)=s\}}$, where both *n(t) and n(t-1)* satisfy $n(t) = st + b_0 (\mathrm{mod}\, N)$.

31. The method as defined in claim 29 wherein said frequency shift is estimated in accordance with $\hat{b}_0 = \arg \max_{b_0=0,...,N-1} \sum_{t=0}^{N_{sy}-1} E(t) \mathbf{1}_{\{n(t)=st+b_0\}}$.

32. The method as defined in claim 27 wherein said step of maximum energy detecting includes a step of finding the time, $t_0 \in T$, and slope, $s_0 \in S$, such that the set of times t on the line $n(t) = n(t_0) + s_0 (t - t_0)$, has the largest total pilot signal energy.

33. Apparatus for use in a mobile user unit in an orthogonal frequency division multiplexing (OFDM) based spread spectrum multiple access wireless system comprising the steps of:

means for receiving one or more pilot tone hopping sequences each including pilot tones, said pilot tones each being generated at a prescribed frequency and time instants in a prescribed time-frequency grid; and

means, responsive to said one or more received pilot tone hopping sequences, detecting the received pilot tone hopping sequence having strongest power.

34. The invention as defined in claim 33 wherein each of said one or more pilot tone hopping sequences is a Latin Squares based pilot tone hopping sequence.

35. The invention as defined in claim 33 wherein said means for receiving yields a baseband version of a received signal and further including means for generating a fast Fourier transform version of said baseband signal, and wherein said means for detecting is responsive to said fast Fourier transform version of said baseband signal for determining a received pilot tone sequence having the strongest power.

36. The invention as defined in claim 35 wherein said means for generating said fast Fourier transform includes means for quantizing the results of said fast Fourier transform.

37. The invention as defined in claim 35 wherein means for detecting detects a maximum energy.

38. The invention as defined in claim 37 wherein said means for detecting said maximum energy includes means for determining a slope and initial frequency shift of pilot tones in a detected pilot tone hopping sequence having the strongest power.

39. The invention as defined in claim 38 wherein said means for detecting said maximum energy includes means for accumulating energy along each possible slope and initial frequency shift of said one or more received pilot tone hopping sequences, means for generating an accumulated energy signal, means, responsive to said accumulated energy signal, for accumulating energy along pilot frequency shifts of said one or more received pilot tone hopping sequences, and means, responsive to an output from said means for frequency shift accumulating, for estimating a slope and initial frequency shift

of the strongest received pilot tone hopping sequence as a slope and initial frequency shift corresponding to he strongest accumulated energy.

40. The invention as defined in claim 39 wherein said accumulated energy is represented by the signal $J_0(s,b_0)$, where $J_0(s,b_0) = \sum_{t=0}^{N_{sy}-1} | Y(t, st + b_0 (\mathrm{mod}\, N)) |^2$, and s is the slope of the pilot signal, b_0 is an initial frequency shift of the pilot signal, *Y(t,n)* is the fast Fourier transform data, $t = 0, \ldots N_{sy} - 1$, $n = st + b_0 (\mathrm{mod}\, N)$, and $n = 0, \ldots N\text{-}1$.

41. The invention as defined in claim 39 wherein said means for frequency shift accumulating includes means for accumulating energy along pilot frequency shifts of said one or more received pilot tone hopping sequences in accordance with $J(s,b_0) = \sum_{j=1}^{N_p} J_0(s, b_0 + n_j)$, where s is the slope of the pilot signal, b_0 is an initial frequency shift of the pilot signal and n_j are frequency offsets.

42. The invention as defined in claim 39 wherein said means for maximum energy detecting includes means for estimating said slope and initial frequency shift of the strongest received pilot tone hopping sequence in accordance with $\hat{s}, \hat{b}_0 = \arg\max_{s,b_0} J(s,b_0)$, where $\hat{s}$ is the estimate of the slope, $\hat{b}_0$ is the estimate of the initial frequency shift, and where the maximum is taken over $s \in S$ and $b_0 = 0, \ldots, N-1$.

43. The invention as defined in claim 37 wherein said means for maximum energy detecting includes means for estimating at a given time frequency shift of the received pilot tone hopping sequence having strongest energy and for estimating a maximum energy value, and means, responsive to said estimated frequency shift and said estimated maximum energy value, for generating estimates of an estimated slope and an estimated initial frequency shift of the strongest received pilot signal.

44. The invention as defined in claim 43 wherein said estimated frequency shift at time t is obtained in accordance with $n(t) = st + b_0 (\mathrm{mod}\, N)$, where s is the pilot signal slope, t is a symbol time and *n(t)* is a frequency shift estimate.

45. The invention as defined in claim 44 wherein said estimated maximum energy value is obtained in accordance with $[E(t),n(t)] = \max_{n} \sum_{j=1}^{N_p} | Y(t, n + n_j \pmod N) |^2$, where $E(t)$ is the maximum energy value, $Y(t,n)$ is the fast Fourier transform data, $j = 1, \ldots, N_p$ and n_j are frequency offsets.

46. The invention as defined in claim 45 wherein said slope is estimated in accordance with $\hat{s} = \arg\max_{s \in S} \sum_{t=1}^{N_{sy}-1} E(t)\mathbf{1}_{\{n(t)-n(t-1)=s\}}$, where both $n(t)$ *and* $n(t\text{-}1)$ satisfy $n(t) = st + b_0 \pmod N$.

47. The invention as defined in claim 45 wherein said frequency shift is estimated in accordance with $\hat{b}_0 = \arg \max_{b_0=0, \ldots N-1} \sum_{t=0}^{N_w-1} E(t)\mathbf{1}_{\{n(t)=st+b_0\}}$.

48. The invention as defined in claim 43 wherein said means for detecting maximum energy includes means for finding the time, $t_0 \in T$, and slope, $s_0 \in S$, such that the set of times t on the line $n(t) = n(t_0) + s_0(t - t_0)$, has the largest total pilot signal energy.

Abstract of the Disclosure

A base station having the strongest downlink signal is identified by utilizing a unique slope of a pilot tone hopping sequence being transmitted by a base station. Specifically, base station identification is realized by determining the slope of the strongest received pilot signal, i.e., the received pilot signal having the maximum energy. In an embodiment of the invention, the pilot tone hopping sequence is based on a Latin Squares sequence. With a Latin Squares based pilot tone hopping sequence, all a mobile user unit needs is to locate the frequency of the pilot tones at one time because the pilot tone locations at subsequent times can be determined from the slope of the Latin Squares pilot tone hopping sequence. The slope and initial frequency shift of the pilot tone hopping sequence with the strongest received power is determined by employing a unique maximum energy detector. In one embodiment, the slope and initial frequency shift of the pilot signal having the strongest received power is determined by finding the slope and initial frequency shift of a predicted set of pilot tone locations having the maximum received energy. In another embodiment, the frequency shift of the pilot signal with the strongest, i.e., maximum, received power is estimated at each of times "t". These frequency shifts are employed in accordance with a prescribed relationship to determine the unknown slope and the initial frequency shift of the pilot signal.

QUALCOMM-054000

FIG. 1

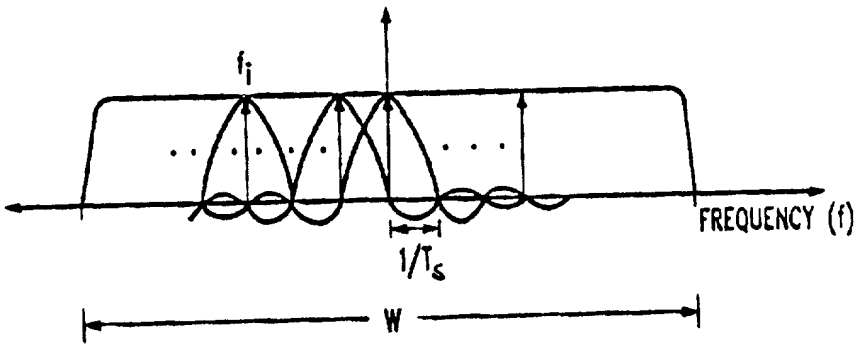

FIG. 2

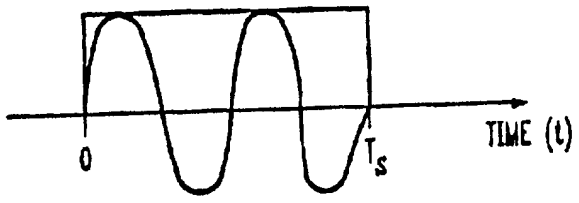

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FIG. 3

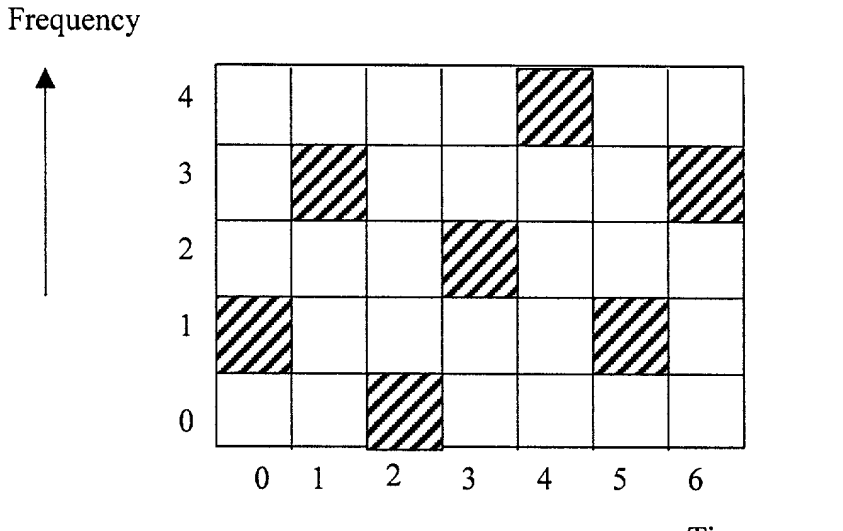

FIG. 4

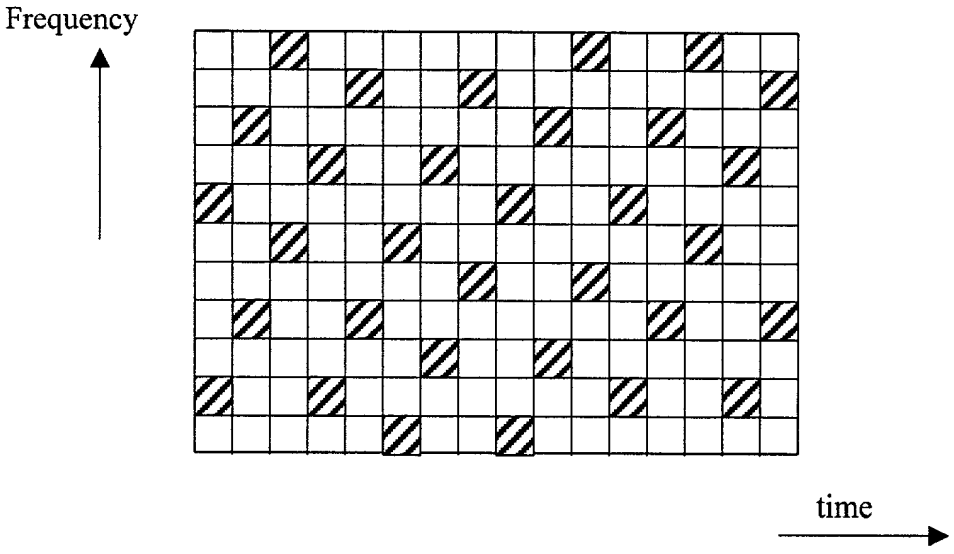

FIG. 5

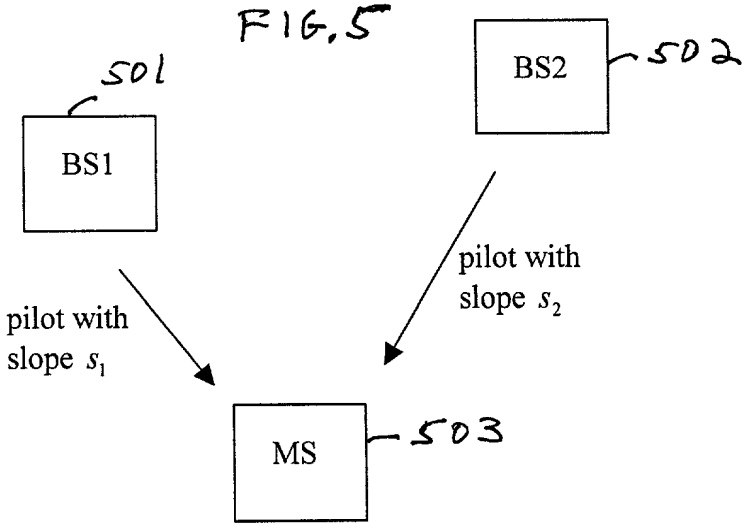

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FIG. 6

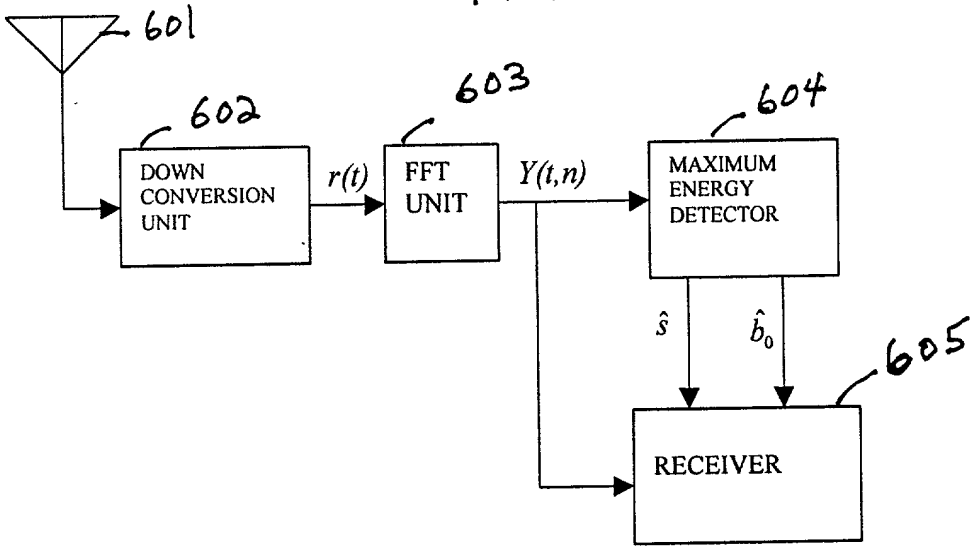

FIG. 7

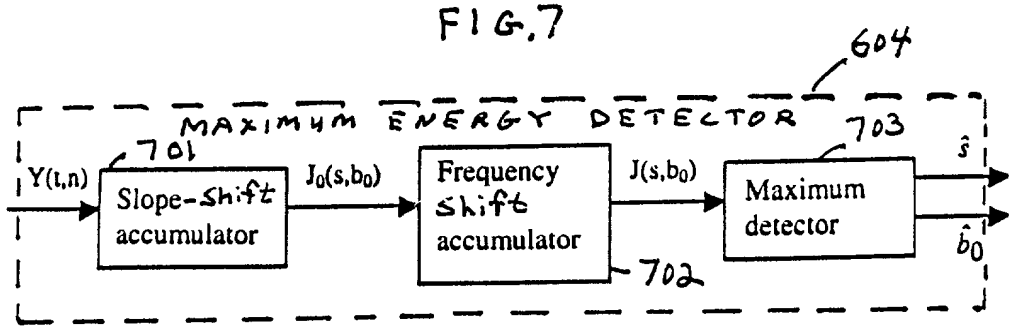

FIG. 8

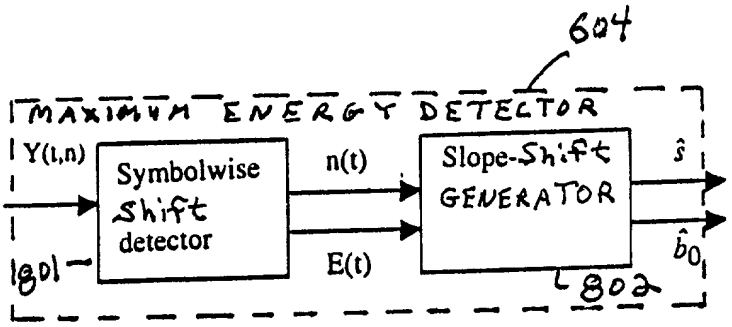

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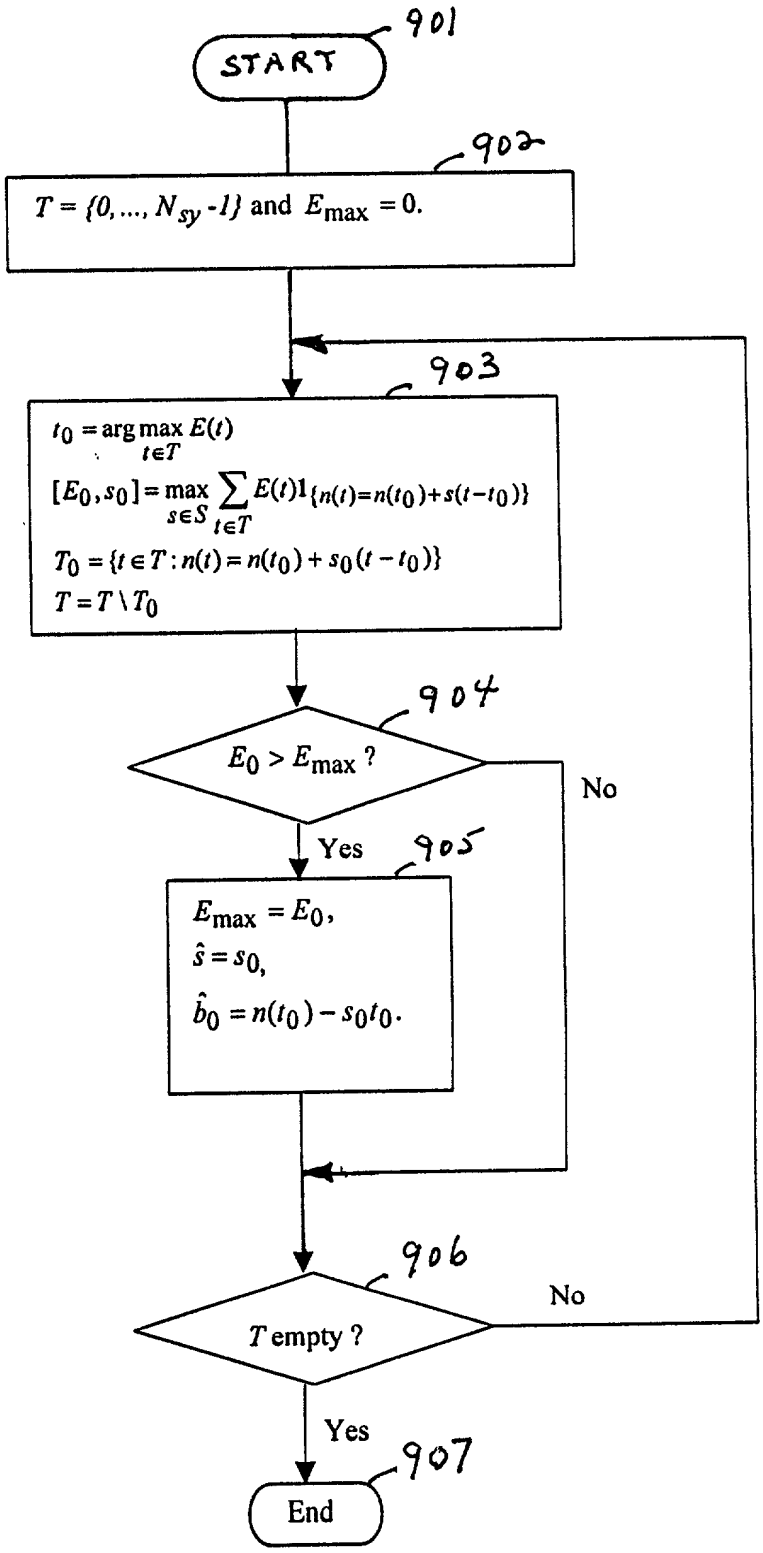
FIG. 9



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IN THE UNITED STATES
PATENT AND TRADEMARK OFFICE

Declaration and Power of Attorney

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **BASE STATION IDENTIFICATION IN ORTHONGONAL FREQUENCY DIVISION MULTIPLEXING BASED SPREAD SPECTRUM MULTIPLE ACCESS SYSTEMS** the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by an amendment, if any, specifically referred to in this oath or declaration.

I acknowledge the duty to disclose all information known to me which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

None

I hereby claim the benefit under Title 35, United States Code, 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

None

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

QUALCOMM-040900

I hereby appoint the following attorney(s) with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected therewith:

Lester H. Birnbaum	(Reg. No. 25830)
Richard J. Botos	(Reg. No. 32016)
Jeffery J. Brosemer	(Reg. No. 36096)
Kenneth M. Brown	(Reg. No. 37590)
Craig J. Cox	(Reg. No. 39643)
Donald P. Dinella	(Reg. No. 39961)
Guy Eriksen	(Reg. No. 41736)
Martin I. Finston	(Reg. No. 31613)
James H. Fox	(Reg. No. 29379)
William S. Francos	(Reg. No. 38456)
Barry H. Freedman	(Reg. No. 26166)
Julio A. Garceran	(Reg. No. 37138)
Mony R. Ghose	(Reg. No. 38159)
Jimmy Goo	(Reg. No. 36528)
Anthony Grillo	(Reg. No. 36535)
Stephen M. Gurey	(Reg. No. 27336)
John M. Harman	(Reg. No. 38173)
Michael B. Johannesen	(Reg. No. 35557)
Mark A. Kurisko	(Reg. No. 38944)
Irena Lager	(Reg. No. 39260)
Christopher N. Malvone	(Reg. No. 34866)
Scott W. McLellan	(Reg. No. 30776)
Martin G. Meder	(Reg. No. 34674)
John C. Moran	(Reg. No. 30782)
Michael A. Morra	(Reg. No. 28975)
Gregory J. Murgia	(Reg. No. 41209)
Claude R. Narcisse	(Reg. No. 38979)
Joseph J. Opalach	(Reg. No. 36229)
Neil R. Ormos	(Reg. No. 35309)
Eugen E. Pacher	(Reg. No. 29964)
Jack R. Penrod	(Reg. No. 31864)
Daniel J. Piotrowski	(Reg. No. 42079)
Gregory C. Ranieri	(Reg. No. 29695)
Scott J. Rittman	(Reg. No. 39010)
Eugene J. Rosenthal	(Reg. No. 36658)
Bruce S. Schneider	(Reg. No. 27949)
Ronald D. Slusky	(Reg. No. 26585)
David L. Smith	(Reg. No. 30592)
Patricia A. Verlangieri	(Reg. No. 42201)
John P. Veschi	(Reg. No. 39058)
David Volejnicek	(Reg. No. 29355)
Charles L. Warren	(Reg. No. 27407)
Jeffrey M. Weinick	(Reg. No. 36304)
Eli Weiss	(Reg. No. 17765)

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I hereby appoint the attorney(s) on ATTACHMENT A as associate attorney(s) in the aforementioned application, with full power solely to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected with the prosecution of said application. No other powers are granted to such associate attorney(s) and such associate attorney(s) are specifically denied any power of substitution or revocation.

Full name of 1st inventor: Rajiv Laroia
signature_____Date_____

Residence: Basking Ridge, Somerset County, New Jersey

Citizenship: India

Post Office Address: 455 Somverville Road
Basking Ridge, New Jersey 07920

0956-0978-0US00

Full name of 2nd inventor: Junyi Li
Inventor's
signature_____Date_____

Residence: Matawan, Monmouth County, New Jersey

Citizenship: Peoples Republic of China

Post Office Address: Matawan Terrace Apartments
Apt. 104
Matawan, New Jersey 07747

DOCKET NO. 080336

Full name of 3rd inventor: Sundeep Rangan
Inventor's
signature_____Date_____

Residence: Hoboken, Hudson County, New Jersey

Citizenship: Canada

Post Office Address: 156 7th Street
Apt. B
Hoboken, New Jersey 07030

0552.0800

Full name of 4th inventor: Pramod Viswanath
Inventor's
signature_____Date_____

Residence: Berkeley, Alameda County, California

Citizenship: India

Post Office Address: 128 Wilson Street
Berkeley, California 94706

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ATTACHMENT A

Attorney Name(s): Thomas Stafford Reg No.: 24767

Telephone calls should be made to Thomas Stafford, Patent Attorney at:

Phone No.: 727-772-4173

Fax No.: 727-772-2545

All written communications are to be addressed to:

THOMAS STAFFORD
PATENT ATTORNEY
4173 Rotherham Court
Palm Harbor, Florida 34685

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